NASA TECHNICAL TRANSLATION NASA TT F-14476

STUDY OF THE PHYSICAL STATE OF BREAKDOWN PRODUCTS BY LASER ACTION ON CONDENSED MEDIA

by
M. A. Yel'yashevich, V.K. Goncharov, L.Ya. Min'ko, G.S. Romanov

Translation of "Izucheniye fizicheskogo sostoyaniya produktov razrusheniya pri lazernom vozdeystvii na kondensirovannyye sredy," Zhurnal prikladnoy spectroskopii, Vol. 15, No. 2, August 1971, pp. 200-204.

(NASA-TT-F-14476) STUDY OF THE PHYSICAL STATE OF BREAKDOWN PRODUCTS BY LASER ACTION ON CONDENSED MEDIA M.A. Yel'yashevich, et al (Kanner (Leo) Associates) Mar. 1972 8 p
N72-32520
Unclas
CSCL 20E G3/16 43348

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 MARCH 1972

Zhurnal prikladnoy spektroskopii, Vol. 15, No. 2, August 1971, pp. 200-204

STUDY OF THE PHYSICAL STATE OF BREAKDOWN PRODUCTS BY LASER ACTION ON CONDENSED MEDIA*

by

M.A. El'yashevich, V.K. Goncharov, L.Ya. Min'ko, G.S. Romanov

Laser emission of intensity of the order of 10^6 to 10^8 W/cm^2 is a highly convenient method of producing dense low-temperature plasma of well-defined composition by its action on absorptive media. In this connection, the investigation of processes leading to the formation of plasma and the shaping of the plasma jet, the study of its structure and optical and gas dynamics characteristics are of great interest. In this project, special attention was devoted to the study of the kinetics of such phenomena, necessary for understanding the whole aggregate of phenomena observed during laser action on metals. To this end, an ordered generation mode was devised, enabling production of relatively uniform emission pulses with adequate time interval.

Figure 1 shows a diagram of the setup. A 25 x 250 mm neodymium rod served as the operating element of the generator, providing emission energy of ~60 J. To produce the ordered generation mode, a planesphere resonator was used; the spherical mirror (R = 2.5 m) had the maximum coefficient of reflection, the plane, 25%. Figure 2 shows typical oscillograms of emission.

Focusing emission on the target was done by a lens of 100 mm focal length. Investigations were accomplished at atmospheric pressure and a little lower (to 10^{-3} mm/Hg). Development of the plasma jet in time and the kinetics of

*A report read at the Third All-Union Thermodynamic Conference on Properties of Substances at High Temperatures (Baku, October, 1968).

Details of illustrations in this document may be better studied on microfiche

the breakdown process were studied with the aid of high speed photographic equipment SFR-1 and ZhFR-2 in continuous mode with time resolution to 10^{-7} sec. For generation of plasma jets, samples of different metals were subjected to laser action. Ordinary metallic plates served as test samples, also quartz and metal glued together according to the procedure in reference [1], and metallic rods placed inside the capillary, excluding the possibility of developing the jet at the target surface. Change of flux density on the target was realized by changing pumping energy and by using the focusing system. Flux densities attained in the experiment did not exceed 10^3 W/cm^2, i.e., they lay in the correct range of the thermal breakdown mechanism [1].

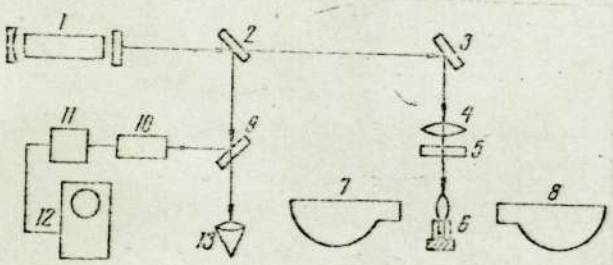


Fig. 1 Diagram of the installation. 1. laser; 2, 9. translucent and 3. reflective mirrors; 4. focusing lens; 5. protective glass; 6. test sample; 7,8. photographic equipment ZhFR-2 and SFR-1; 10. photocell F5; 11. cathode follower; 12. oscillograph OK-17M; 13. calorimeter IF-68.

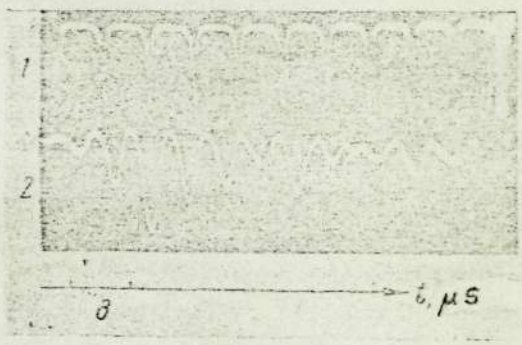


Fig. 2 Oscillograms of emission. 1. ordered mode; 2. chaotic mode.

Breakdown products formed by the action of laser emission on metal discharged into the peripheral space in the form of a supersonic jet, perpendicular to the surface of the metal and of the complex component composition. Examination of the process of forming and dispersing of the breakdown products [2]

gives the following gas dynamics picture of the flow. Acceleration of the vaporized substance to a speed on the order of the speed of sound occurs in a thin layer at the surface with a thickness of a few free path lengths of vapor particles. During this process the vapor cools sharply and changes to an unstable supersaturated state, which further changes to a condition close to saturated, due to the formation of a condensation jump. At this, temperature of the plasma flow increases to a temperature near that of the surface. Thickness of the zone occupied by the condensation jump, in which the temperature rise occurs, is of the order of magnitude of $\lesssim 10^3$ free path lengths of vapor particles and at low flux emission density may reach $\sim 10^{-1}$ cm. Further expansion and acceleration of the forming jet occur in the rarefaction wave, whereupon, due to the cooling of the breakdown products under certain conditions, the material condenses into droplets the ultimate size of which can attain $\sim 10^{-5}$ to 10^{-4} cm. Due to the release of internal energy upon condensation, an increase in flow velocity must occur, as well as a change in the profile of values (density, temperature, pressure) compared to a situation without such a process.

To study the structure and mechanism of formation, and also to clarify the effect of the processes taking place in the jets on the kinetics of material breakdown, continuous photographs were taken. Long resolution time photography permitted the study of plasma flow structure in more detail. As seen from the photographs in Figure 3a, each separate plasma clusters, corresponding to specific peaks of emission, have in their turn a complex structure. It appears to consist of two clusters, one which quickly loses its speed, another which continues to propagate with relatively high speed. It may be assumed [3] that the boundary between these clusters, seen in the photographs

as increases in emission intensity, is a condensation jump arising as a result of sharp overexpansion of the plasma clusters. Indeed, it may be seen that the "rise" of the second clusters occurs at the end of the discharge when emission intensity falls off and plasma formation is curtailed. At atmospheric pressure, at some range from their base, a jump in intensity of illumination is also found in plasma clusters (see Fig. 3a). In front of the jump, an area of weak illumination is seen. The presence of condensation jumps in the plasma clusters attests to the supersonic speed of their emission in conditions of underexpansion, i.e., each separate plasma cluster is in miniature a jet, flowing from the nozzle (crater) with excess pressure [4]. In some cases the photography shows (see Fig. 3b) periodic increases in illumination intensity, caused by the formation of a periodic structure with the flow of a supersonic jet in conditions of underexpansion, i.e., during relatively low pressure differential between the jet and the surrounding material. The above-mentioned character of the flow has been thoroughly investigated for pulse generator plasma jets [5].

During the process of emission incident on a series of metals in a vacuum chamber (at pressure of $\sim 10^{-2}$ mm/Hg), condensate particles are seen forming in the process of jet development. Their size is $\sim 10^{-5}$ to 10^{-4} cm, which agrees with the values calculated above. Particles are especially well fixated by action on an aluminum target. For detection of condensate, at a distance of 10 cm from the target a glass strip was placed normal to the direction of jet propagation, on which a uniform background of small spherical particles $\sim 10^{-5}$ to 10^{-4}, in addition to the liquid phase particles (size $\sim 10^{-2}$ to 10^{-1} cm) may be seen with a microscope. The former are ingrained as a result of the high speed of the jet to the glass strip.

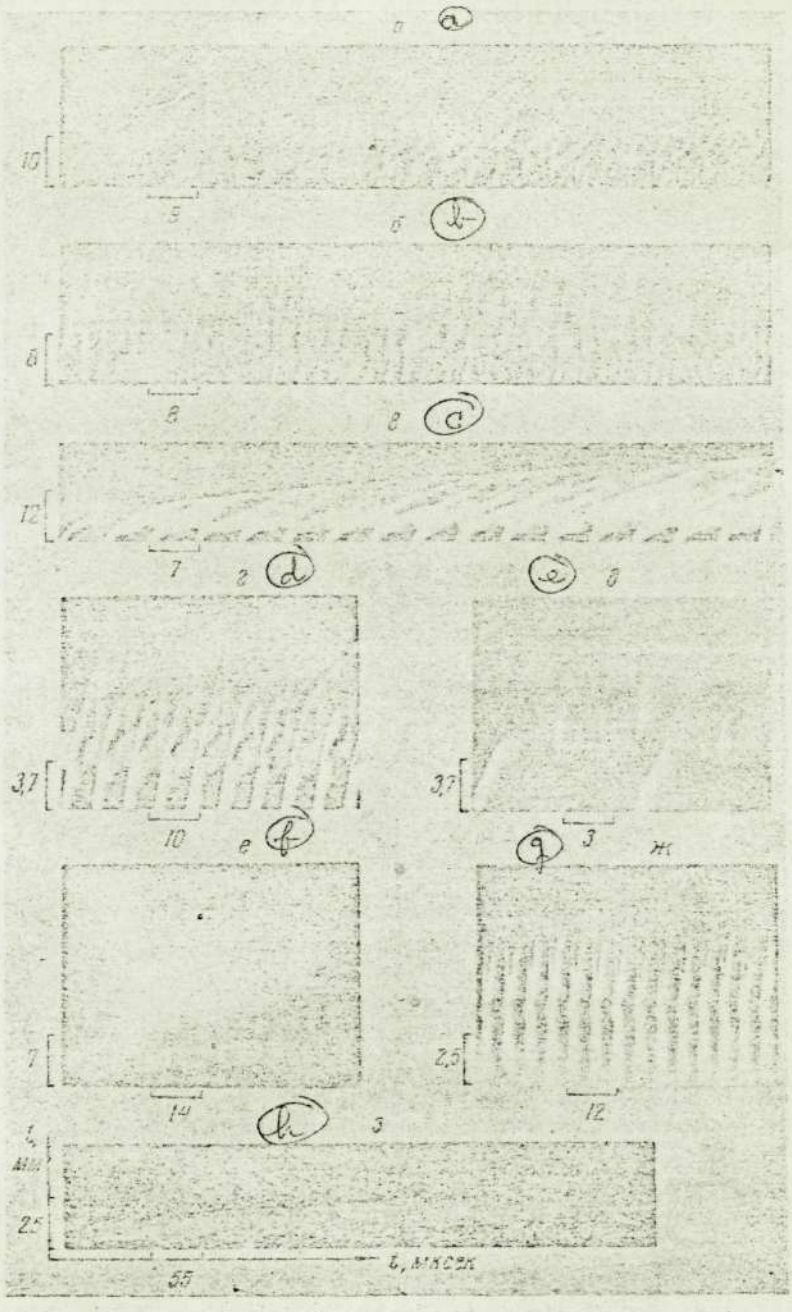


Fig. 3 Photography of plasma jets. a,c,d,e. fragmentary photograph of action on a zinc strip; b. on a brass strip in chaotic generation mode; f. on POS-40 alloy in the capillary; g. on quartz and POS-40 alloy glued together; h. on metallic lithium

The photography shows vertical bands (see Fig. 3c-e) in addition to the separate plasma clusters. They are shown especially clearly during the action of the laser emission on the target in the capillary. Special experiments were performed, in which the possibility of expansion of the plasma jet was limited. In some cases, multiple effects were produced in one and the same crater; in others, the plasma jet developed the quartz capillary in which the test sample was located. In these cases, relatively intense absorption of the incident laser emission was observed all the way down to its extinction. This is shown by the intense vertical bands on the photograph of the process of flow of the developing breakdown products (See Fig. 3f,g). For some metals and alloys, for example the alloy POS-40 (and in the case of Li during action on an open surface), enough plasma was formed during the action of the first few peaks (see Fig. 3h) for full screeeing of the target surface. This shows that supplementary initial heating of plasma occurs during action of preceding emission pulses with following pulses, i.e., an increase of brightness because of absorption of laser emission. As a result, partial screening of the target surface from the action of laser emission occurs. During development of the process, a buildup of plasma clusters occurs,and surface screening becomes stronger. In the photograph this is seen as periodic "scintillation" of plasma clusters (see Fig. 3d). Of the materials investigated, the greatest emission absorption in breakdown products at a density of $\sim 10^7$ to 10^8 W/cm^2 was observed for W, Li, Al; for Cu, Fe, Pb and Zn, absorption turned out to be less, which is in agreement with the computed data of reference [6].

In some instances, an increase in speed of plasma jet flow was observed. This is easily seen by the increase in angle of inclination of the leading edge of luminescence of the cluster (see Fig. 3e). With each succeeding passage of emission through the cluster, its speed increases.

Comparative spectroscopic analyses of the plasma jet developing during action of laser emission on metals, and also of the erosional plasma jet during high current pulse discharge detected a close analogy in physical state of plasma developing in both cases during comparable energy flows of $\sim 10^7$ to 10^8 W/cm^2. The exitation of the spectrum is of thermal character; an intensive continuous spectrum is observed as well as an intense broadening of separate spectral lines. The exitation temperature is ~5000 to 20,000° C; concentration of charged particles is $\sim 10^{17}$ to 10^{13} cm^{-3} during discharge of plasma from the erosional crater.

Bibliography

[1] Anisimov, S.I., A.M. Bonch-Bruevich, M.A. El'yashevich, Ya.A. Imas, N.A. Pavlenko, G.S. Romanov, *ZhTF*, 34, 1966, 1273.

[2] Romanov, G.S., V.K. Pustovalov, Bulletin of the Academy of Sciences of the Byellorussian Soviet Socialist Republic, Series on Physical-Mathematical Sciences, No. 4, 1967, 84.

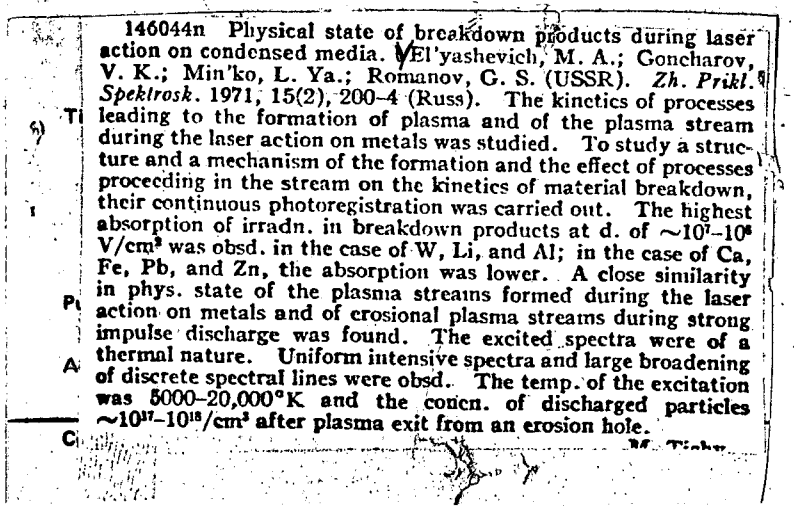
[3] Goncharov, V.K., L. Ya. Min'ko, G.S. Romanov, *Fizika i khimiya obrabotki materialov*, No. 3, 1968, 149.

[4] Bakanovich, G.I., L.I. Grechikhin, L.Ya. Min'ko, collected articles "Applied Spectroscopy," Vol. 1, Moscow, Nauka Press, 1969, p. 95; L.A. Grechikhin, L.Ya. Min'ko, *ZhTF*, 8, 1968, 753.

[5] Grechikhin, L.I., L.Ya. Min'ko, *ZhTF*, 32, 1962, 1074; *PMTF*, No. 3, 1965, 77.

[6] Romanov, G.S., K.L. Stepanov, *ZhPS*, 8, 1968, 753.

Translated from the original Russian by LEO KANNER ASSOCIATES, P.O. Box 5187, Redwood City, California 94063, (415) 365-3046, February 1972



146044n Physical state of breakdown products during laser action on condensed media. El'yashevich, M. A.; Goncharov, V. K.; Min'ko, L. Ya.; Romanov, G. S. (USSR). *Zh. Prikl. Spektrosk.* 1971, 15(2), 200-4 (Russ). The kinetics of processes leading to the formation of plasma and of the plasma stream during the laser action on metals was studied. To study a structure and a mechanism of the formation and the effect of processes proceeding in the stream on the kinetics of material breakdown, their continuous photoregistration was carried out. The highest absorption of irradn. in breakdown products at d. of $\sim 10^7$–10^8 V/cm was obsd. in the case of W, Li, and Al; in the case of Ca, Fe, Pb, and Zn, the absorption was lower. A close similarity in phys. state of the plasma streams formed during the laser action on metals and of erosional plasma streams during strong impulse discharge was found. The excited spectra were of a thermal nature. Uniform intensive spectra and large broadening of discrete spectral lines were obsd. The temp. of the excitation was 5000–20,000°K and the concn. of discharged particles $\sim 10^{17}$–10^{18}/cm^3 after plasma exit from an erosion hole.